REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
27-02-2006	Conference Proceedings	22 September 2004 - 25 September 2004

4. TITLE AND SUBTITLE

ICES/COST 281 Thermal Physiology Workshop

5a. CONTRACT NUMBER
FA8655-04-1-5064

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Conference Committee

5d. PROJECT NUMBER

5d. TASK NUMBER

5e. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

INERIS
Parc Alata - BP2
Verneuil-en-Halatte 60-550
France

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0014

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
CSP 04-5064

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited. (approval given by local Public Affairs Office)

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Final Proceedings for ICES/COST 281 Thermal Physiology Workshop, 22 September 2004 - 25 September 2004

The goal of the workshop is to develop appropriate techniques for predicting the thermophysiological responses of humans who are exposed to RF/MW fields at specific frequencies, field strengths, and dosimetry, both experimental and theoretical. We will validate modeling predictions with existing human exposure data. Topics include: Environmental physiology under heat stress (whole body and selected tissues); Descriptions of available models (physiological, dosimetric, and FD-TD);Techniques for combining models with classical physiological data and theoretical and experimental RF dosimetry.

15. SUBJECT TERMS

EOARD, Physiology, Thermoregulation, Thermal Stress, Radio Frequency Safety and Health

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18, NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			ROBERT N. KANG, Lt Col, USAF
UNCLAS	UNCLAS	UNCLAS	UL	40	19b. TELEPHONE NUMBER *(Include area code)* +44 (0)20 7514 4437

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39-18

Report of the IEEE ICES/COST 281 Thermal Physiology Workshop, Paris, France, Sept 22-24, 2004, prepared by Eleanor R. Adair, Ph.D.

The ICES/COST 281 Thermal Physiology Workshop was held at INERIS, Verneuil-en-Halatte (north of Paris), on September 22 - 24, 2004. This workshop was preceded by a two-day COST 281 Workshop on EMF Research and Dosimetry, held in Paris on September 20 - 21. Dr. René de Seze of INERIS was in charge of the arrangements for and co-chair of the back-to-back workshops. Some participants in the ICES/COST 281 workshop also attended the earlier COST 281 workshop.

Background for the Workshop.

For some time, it has been a major goal of many scientists to combine our knowledge of basic human thermal physiology with changes that occur when humans are exposed to thermal stress (heat). This stress can be natural environmental heating, elevated body temperatures during work and exercise, and, specifically, in persons exposed to radio frequency (RF) and microwave (MW) fields. Since data on human volunteers exposed to RF/MW fields are minimal, we need to develop a method to predict how humans of various ages, sizes, fitness, and environmental sensitivity would respond to different RF/MW frequencies, field strengths, durations, modulations, etc. It is important to combine our knowledge of both human thermoregulation and careful RF dosimetry so that we can model thermoregulatory responses of humans exposed to these fields. At a combined meeting of IEEE ICES and ICNIRP members, held in January 2001, the ICNIRP Chairman proposed that the two committees arrange to support a Thermal Physiology Workshop that could be held in either 2002 or 2003 at a convenient site. This proposal was greeted with much enthusiasm and Eleanor R. Adair offered to submit some background material, a possible agenda, a list of potential participants, and their role in the workshop.

The idea of a Thermal Physiology Workshop was also important to scientists concerned with potential hazards of RF fields from cell phones and other electronic devices. With the support of several cell phone manufacturers, the Mobile Manufacturers Forum (MMF), and the World Health Organization (WHO), a two-day workshop concerning thermal effects of RF exposure on cells, tissues, and organs was scheduled in Geneva for the fall of 2001. The workshop was postponed following the 9/11 terrorist attacks, but met at the WHO Geneva headquarters in March, 2002. Heating of all or part of the body was the focus of the workshop, with special emphasis on RF heating of cells, tissues, and organs. A set of valuable papers, based on the workshop discussions and expertise of several key speakers, was published in 2003 in the International Journal of Hyperthermia.

Although the Geneva workshop had a different focus from the original proposal, several individuals felt it would be valuable to follow up with a second workshop similar to that

originally proposed. I was pleased to learn from Tom McManus that the possibility of another Thermal Physiology Workshop was discussed at the Fall 2003 COST 281 meeting in Dublin. Strong interest in a collaborative effort between COST 281 and IEEE ICES to hold such a workshop in the Fall of 2004 was presented by Norbert Leitgeb. The U.S. Air Force, through their European office EOARD, offered to provide considerable support for this workshop. Additional support was provided by COST 281, INERIS, and IEEE ICES. A revised proposal for the workshop was drafted that included the goals of the workshop, a proposed agenda, and a list of potential invited speakers, participants, and observers. The details are given below.

Goals of the Workshop.

The primary goal of the workshop was to develop appropriate techniques for predicting the thermophysiological responses of human beings who are exposed to RF/MW fields at specific frequencies, field strengths, and field characteristics and to validate some predictions with existing human exposure data. A primary focus on RF/MW bioeffects, their dosimetry and prediction through modeling, would provide an enhancement of our capability to set science-based safety standards for human exposure to electromagnetic fields.

The relationship between temperature and time required to produce tissue damage was published in 1947 by Moritz and Henriques, and the discipline of environmental physiology has been ongoing since the mid-1800s. Masses of data exist that describe the regulatory response changes in the human body as a function of environmental variables, work, exercise, age, fitness, clothing insulation, and other characteristics of each individual. Much of this material is amenable to comparison with data derived from RF/MW-exposed humans and animals. The first goal would be to bring together expert environmental physiologists to present the current state of knowledge. Two or more of these individuals should be drawn from those who attended the Geneva Workshop, to present specifics on thresholds for thermal hazard to cells, tissues, and organs

Since experimental data concerning RF/MW exposures of humans are sparse, it is essential to have a method or methods, to predict the results of conditions that have not yet been studied experimentally. These methods appear to be models of two general types: models based on human thermal physiology, such as compartmental models, and models based on RF energy absorbed by the body, such as FDTD models. Several scientists are currently working on both types of models across a range of RF frequencies, with highly promising results. Many of these scientists should interact with the environmental and cellular physiologists in the application of their modeling techniques.

If one or more types of models are combined with appropriate physiological and dosimetric data, it will be important to validate the predictions of the models. Data already collected on human volunteers exposed to RF energy at several frequencies and field strengths are available to compare with predictions at those same frequencies and field strengths. For example, a 27-node model developed by Stolwijk and Hardy [1966];

Stolwijk, [1983] has been used to predict, with reasonable accuracy, the physiological responses of human volunteers exposed to 100, 450, and 2450 MHz CW in controlled thermal environments [Foster and Adair, 2004]. Accurate predictions of other types of models, developed in this workshop, will greatly enhance the probability that modeling will become a useful tool to determine RF safe exposure levels and hazard thresholds across the RF/MW spectrum for many classifications of people.

Proposed Agenda for the Workshop.

A proposed three-day Thermal Physiology Workshop was approved by the officers of COST 281 and was scheduled to be held at the Institut Nationale de l'Environnement industriel et des RISques (INERIS), outside Paris, on September 22 – 24, 2004. The workshop was co-sponsored by the IEEE International Committee on Electromagnetic Safety (ICES) and COST 281. Dr. René de Seze of INERIS was in charge of the local arrangements and co-chaired the meetings together with Dr. Eleanor Adair.

Day 1 of the ICES/COST 281 workshop was devoted to presentations by each of the invited participants. It began with welcoming speeches, technical details, and a keynote speaker who presented background material and set out the goals of the workshop. The presentations of ~10 min each, then proceeded in 3 sections: 1) Environmental physiology under heat stress, including both whole body and selected tissues; 2) Descriptions of types of models currently available, including physiological and dosimetric models; and 3) Possible techniques for combining models with classical physiological data and basic theoretical and experimental RF dosimetry. Each invited participant was asked to provide an abstract prior to the workshop, and a draft manuscript in his/her field of endeavor by 1 November 2004. The program of speakers and topics will be found in a separate section below and the submitted abstracts are also included in the order presented.

Day 2. The morning was devoted to the selection of three simultaneous discussion groups charged with defining the optimal data to use, the types of modeling that would be useful to generate predictions of human responses, and critical questions that needed clarification. One group was the Thermal Physiology Working Group, the second a Whole-body Working Group, and the third a Partial-body Working Group. Each group selected a chairman who was responsible for providing a report of deliberations later in the day.

Day 3. After a session involving further discussion of the Bioheat equation, two new breakout working groups were established, one partial-body and the other whole-body. Each group included some of the thermal physiologists. The Partial-body Working Group was chaired by Joe Wiart and the Whole-body Working group was chaired by Kenneth Foster. Each group finalized a report for presentation later in the day. Because the Partial-body group needed more time to finalize their report, David Nelson gave a presentation concerning parametric analyses. The reports of the two groups were presented and discussed in the afternoon. A final concluding session was held with regard to specific recommendations (action items) contributed by both participants and

organizers. The workshop concluded with a guided visit and formal banquet at the Chateau de Chantilly.

Reports of the Thursday and Friday Whole-body and Partial-body Working groups and the Thursday Thermal Physiology Working Group

Report of Thermal Physiology Group
Thursday, 23 September, 2004

1. We report all findings but only take issue with findings previously demonstrated to be useful for health risk assessment.
    a. Selected changes in Blood Brain Barrier (BBB) breakdown (permeability) that can be quantified. For this we use the CEM factor to normalize conditions to 43 °C for 60 minutes.
    b. Partial-body values: BBB Breakdown

T (°C)	t (min)	CEM value (min)
42.4	30	13.4
42.1	45	12.9
42.0*	60	15.0
40.0	60	2.0 (for different tissues/astrocytes)

Whole-body values: BBB Breakdown

41.0	600	37.5
40.3	600	14.2**

* This value is the same for an increase in brain blood flow at 42.0 °C
** A clinical change occurs before 40.3 °C
Note that the human breakpoint is 44 °C.

    c. The CEM is an attempt to standardize but is imperfect. Below the break point, every °C below leads to changes of 4 – 6-fold as T goes down [range = 38 – 41 °C]. There are very little data here, especially for humans. We need research in this region.

2. Jack Hoopes has proposed a study to validate SAR values. This involves measurement of T and BF during RF exposure following baseline measurements. He proposes an experiment on an anesthetized live pig. Measurements are made on a cross section of the pig brain. Use of 3 fine Luxtron probes (in hard plastic) inserted initially in 3 dimensions across the brain to the opposite cranium near the ear, which will be the site of the RF exposure. Probes to be withdrawn in very small steps across an equilibrated brain to measure normal T. Blood flow (BF) can also be measured with small laser-doppler probes. Following these baseline data, the probes will be reinserted to their initial positions and the RF energy will be turned on. Upon equilibration, the probes will again be withdrawn in very small steps to measure T and BF. These data will provide ΔTs across the brain tissues and from these values SARs can be calculated. Following the T and BF

measurements, tissue samples can be taken from the region where each probe was drawn. One can get 50 samples per slide. This micro-array will contain 20,000 genes that can be analyzed with proteomics or genomics and perhaps 200 genes will be identified. Pigs are good models for these experiments, but small animals (e.g., rats) can also be used.

3. René de Seze proposed a discussion of the Pennes Bioheat Equation. He wishes to identify and suppress (or add) certain items in the equation that may be irrelevant or known. This will lead to experimental validation. Several items are included in the equation: final T, blood flow, bone and tissue mass, specific heat, and changes in κ with T.

    a. The final T is O.K.
    b. Mass does not matter, e.g., bone
    c. Specific heat is known
    d. Blood flow varies with the duration of the RF exposure, especially changes related to the use of mobile phones. We know that there are sharp changes in muscle and brain blood flow when the tissue temperature reaches 42 °C. To determine changes under conditions of low intensity exposures we need to test for or discover the conditions that produce the changes. Specifically, T changes in the skin under the phone box will impact the T_{blood} as it approaches the skin. L-D BF probes and the introduction of microspheres into the circulation may be possible solutions to determine the T in the epidermis and dermis. For example, if the T_{skin} is at 32 °C initially, it takes ~ 30 minutes for the ΔT_{skin} to come to equilibrium. With the cell phone continually held against the skin all this time, the T_{skin} can exceed 37 °C (Joe Wiart). In this matter, Hoopes proposed another experiment: A Luxtron probe on the skin yields a baseline; then a Luxtron probe is inserted into the epidermal layer parallel to the skin surface; at the same time, another Luxtron probe is inserted into the rectum. The data will show that all of these measurement sites will equilibrate to the same level.
    e. In the bioheat equation there is a problem with κ. Changes in κ need to be explored. For example, κ is null if it depends on T. Also κ can be constant for low intensity exposures. We need a validation of any change in κ - - if it changes, how did this happen?

Preliminary Report of Whole-body Working Group
Thursday, 23 September, 2004

Questions answered or considered:

*Gross physiological responses occur when heat is added to the body.
*Special parts of the body (e.g., hypothalamus) may be critical to thermoregulation.

*Individual differences in subjects (people) may be large.
*FDTD modeling provides good data but it cannot be validated yet except on the body surface.
*The most efficient procedure is to start with a lumped parameter model and then add the FDTD.
* A database can be developed with respect to the thermal characteristics of the tissues. Accuracy is optimistic for simple models but finer grained models may not be in complete agreement.
*In whole-body models there should be relevance to RF biological effects, These may be constrained by many variables, e.g., exercise, clothing, pain, etc., however this question cannot be addressed today
*Detailed T distributions at the organ level are essential but not yet available.
*FDTD dosimetry combined with the modeling of local heat exchange is required.
*Exposure standards for human beings are conservative these days. Simple models can be very useful in providing safe levels of RF exposure.

Preliminary Report of Partial-body Working Group
Thursday, 23 September 2004

Three topics were reported from this working group:

1. What the group did and what model was used.
2. What is the relationship between partial-body and whole-body models with respect to available data and methodologies.
3. How to define a worst case. Some data exist but there is none on the influence of clothing.

Discussion

Adair specified a worst case for an individual person as a $T_{ambient}$ = 37°C, RH = 100% and air movement = 0. Under these conditions neither evaporative nor convective cooling of the body is possible, even if the person is naked. Core temperature will rise at an uncontrollable level.

DeSeze stated that a change in skin temperature from 32 °C to 38 °C (under a mobile phone pressed against the cheek) would be 6 °C and the added RF = 1.5% and κ = 10% locally. Wiart asked if this was for a 1 mm cube. DeSeze gave the 3 options: 10 g of tissue in the shape of a cube yields a SAR of 0.2 W/kg; 1 g of tissue in the shape of a cube yields a SAR of 0.3 W/kg; a 1 mm voxel or 0.1g of tissue in the shape of a cube yields a SAR of 0.5 W/kg. Kuster asked how large a target was being looked at – the answer was one cell.

Hoopes recalled his suggested experiment on T and SAR in the pig brain. He noted that brain tissue is homogeneous and 1 mm^3 of tissue contains 1,000,000 cells.

DeSeze asked what the relevant averaging mass should be. The minimum is the level of the cell, but there is no effect at SAR = 1 W/kg on any averaging mass.

Hoopes has placed catheters in the brains of dogs and has tried to determine reaction times, evidence of risk or harm, etc.

Nelson asked about appropriate test cases and Ziriax was concerned with thermal properties of tissues.

Friday, 24 September 2004

Partial-body and Whole-body Group Reports, including half of the thermal physiologists in each group. These 2 Working Groups combined the theoretical models and the thermal physiology data inputs from Thursday to outline the necessary thermal physiological data to verify one or more dosimetric models.

Group 1: Whole-Body Working Group: RF dosimetry / Modeling techniques / available human data.
Chair: Ken Foster
Group members: John Ziriax, Soichi Watanabe, David Nelson, Larry Berglund, Antonio Faraone, A.R. Curran, Eleanor Adair, and René de Seze.

Report of the Whole-body Working Group

What questions can be addressed today with compartmental models?

Gross physiological responses to heat added to the body (blood flow, sweating, core temperature, skin temperatures, heart rate, metabolic heat production, respiration rate, heat storage)
Effects of environmental variables (ambient temperature, relative humidity, air movement, sources of heat, including RF,..)
Exercise level (age, gender, fitness,)
RF energy to whole body or specific parts of the body (head, torso, extremities,..)
Predict thermal sensations, pain perception, skin burns, etc.
Relevance to RF exposure and biological effects (frequency, duration, polarization, pulsed, CW, frequency modulation, etc.) for interpolation and/or extrapolation of existing data, e.g., Adair's.

What questions cannot be addressed today with compartmental models?

Detailed temperature distributions at organ levels (cm scale) unless modeling of local heat exchange can be incorporated in FDTD dosimetry.

Research questions

Account for subject variability, e.g., age, gender, fitness, (more data would be useful to extend the range of models.) Would febrile subjects be more sensitive? (No, they will freeload on an RF field, not increase heat production, to raise the body temperature to the new set level and maintain the fever until defervescence begins. RF exposure may interfere with defervescence. [Adair, et al., 1997])

Extend compartmental models to include data from individual subjects. Is it feasible to develop a model for certain sensitive populations featuring impaired physiological responses?[Adair and Berglund, 1989 modeled cardiovascular impairment]. Menopausal women, febrile subjects, and young children might be sensitive groups to analyze. (Absolutely not! Maybe the aged and infirm would be, or people on drugs, alcoholics, special physiological problems such as lack of sweat response.) How do we define cohorts, run physiological tests, or use data to determine mathematical models of the cohorts' physiological response? Projects of this kind are nearly impossible to mount, are extremely expensive, require special test environments and signal sources, etc. IRBs discourage studies of human subjects these days. Pigs should make good animal models for humans. Talk to Hoopes about studies on pigs.

Identify T increases in specific parts of the body that have physiological relevance for thermoregulation (e.g., medial preoptic/anterior hypothalamic nuclei, posterior hypothalamus, medulla, spinal cord, deep viscera, skin: all locations where temperature sensitive neurons are found.) Many of these regions have been shown to have high local SARs (> 1 W/kg) that are frequency dependent, as discovered in FDTD models of the visible man (e.g., Ziriax presentation).

It is possible to extend these models to non-compartmental models, but then the parameters cannot be specified.

Availability of a shared database of the thermal properties of biological tissues, their reliability and variability (including references). *Mark Dewhirst has collected much of this material and tables of such properties are available [check with Hoopes]. Nearly all of these data were collected on animals, almost none on humans. Agree on values to be used, if appropriate (Nelson).*

Sensitivity to temperature increase with respect to the thermal properties of biological media. *Determine the media whose parameters may have a more pronounced effect on thermal estimates and perform sensitivity analyses (e.g., DOE) with respect to those parameters. (Nelson presented analysis based on a voxelized model).*

Dependence of thermal parameters of biological media on temperature. *Perhaps a second order effect compared to the temperature dependence of parameters describing the human thermoregulatory system (Not clear what the question is here).*

Dependence on temperature of the parameters describing the human thermoregulatory system. *For compartmental models, the temperature dependencies embedded in the Hardy-Stolwijk model have been verified against some of Adair's data. For more detailed models (e.g., FDTD) such dependencies would have to be estimated or adapted in some way. Reliance on compatible anatomical descriptions or maps may simplify this problem.*

Define and validate "hybrid" compartmental models that combine the advantages of having large compartments (proven to be reliable so far) with the ability of assessing local temperature changes in smaller compartments representing selected organs (define these "sensitive organs" as well based on physiological relevance? Not clear what this means.)

Correlate detailed (voxel?) and compartmental models in order to perform variability analysis on the latter, which is computationally efficient, in order to determine the corresponding fine temperature distributions in the former. *(While this is a worthy exercise, it should be low on the list. The joining of a well-designed compartmental model with an appropriate FDTD dosimetric model should be the first undertaking in this series.)* Material included here is, in many respects, an edited version by E.R. Adair of the Whole-body Working Group Report.

Group 2: Partial-body Working Group: RF dosimetry / modeling techniques and available human data.
Chair: Joe Wiart
Group Members: Niels Kuster, Theodoros Samaras, Peter Wainwright, Ron Petersen, Ralf Bodemann, Akimasa Hirata, Jafar Keshvari, Robert McIntosh, Sheila Johnston, Bernard Billaudel, and Elmountacer Elabbassi.

Report of the partial-Body Working Group

Partial body questions:

- How accurate is/should be the BioHeat Equation (BHE: Pennes, 1948)
    - for small expected increases in temperature (i.e., safety) – according to the discussion the BHE seems to be enough.
    - For excessive increases in expected T (e.g., hyperthermia), the BHE seems not to be enough and vessels (?) are needed
        - Are vessels needed if we are not looking at some specific impact?
        - For local "overexposure" analysis?
        - When do we have to consider that thermoregulation is involved?

    - If thermoregulation is involved, a non-linear / dynamic approach should be required
        - Could we have a "local" thermoregulation? (*Certainly, if you have a local thermal input, e.g. the cheek or arm)*
        - Do we have to take into account the system of whole-body blood perfusion (e.g., local exposure of rat tail should have an influence on the global thermoregulation). *(Normally, changes in local blood flow only accompany that part of the body that is exposed to heat or RF energy. Many environmental factors and exposure parameters control blood pooling and/or distribution in the body.)*

        - What is or should be the influence of global thermoregulation (i.e., blood flow?) on partial-body assessment? What is the influence of the environment on such a relationship? *(See the response to the previous question. This can be a very complicated scenario.)*

- What is the effect of variations in the parameters of the BHE on T or T increase?
    - What is the relationship between these variations?
        - What is the influence of blood perfusion in the skin on the perfusion of the nearest tissues? *(Very little.)*
    - What is the variability of these parameters in the population?
        - It has been reported that the conductivity of the skin can vary by 100%. *(Perhaps so if the skin is wet. But skin wettedness results from sweating that cools the skin through evaporation. Thermal conductivity is a very tiny problem; ± 50% variability is not important [Foster])*
        - Is it coming from measurement or population? *(What is meant here? It makes no sense.)*
        - Is blood perfusion age–dependent? *(This is another complex question. Blood vessels become clogged as people age and blood flow can be impeded partially or totally in certain organs (e.g., the heart). This effect is not something that can be entered in a model – it is far too complex a situation that has little to do with the questions under investigation here. In addition, κ is the most precise term in the whole BHE, i.e., the equation is nonsense from a physical point of view [Foster])*
    - What is the influence of BHE parameters (*which ones?)* on T assessment?
        - The blood flow seems the most important parameter, depending on the tissue under investigation (e.g., the eye)
        - Measurement should be performed on as many tissues as possible. *(This is a huge undertaking and probably will have little value in the long run.)*
    - What information can we get on the water content of tissues related to thermal parameters? *(Body tissues are essentially like H_2O or blood or cerebrospinal fluid. Small changes in T make miniscule changes in conductivity.)*
    - What is or should be the relation between real blood flow and blood flow in the BHE?
- What is the influence of variability in local SAR on T assessment?
    - The SAR depends mainly on the morphology, the segmentation resolution (?), source location and description.
    - What is the influence of local SAR variation, due to the size of each voxel in FDTD modeling, on T assessment? [cf. Gajsek, 2000?]
- What is the influence of age and morphology

    - Is age important? *(It certainly is!)*
    - Morphology and tissue distribution (?)
- What is the effect of real-life scenarios on thermal parameters?
    - Clothing and other insulation
    - Assorted environmental parameters
    - *Activity level*
    - *Health and fitness*
- What is or should be the averaging volume?
    - From the physiological point of view?
    - From the numerical (grid, accuracy of SAR) and intercomparison point of view?
- Where should we estimate the maximum temperature?
    - In important identified tissues, e.g., Maximum T in BBB?
    - In a temperature receptor?
- What are we looking for?
    - A temperature increase?
    - An absolute value with regard to a possible threshold?
- Are we looking for worst-case or an analysis of variations?
    - Are variations of a "normal" person valid (or not) to analyze for worst case?
    - Previous knowledge of SAR, together with thermal and hazard conditions (occupational or accidental), should be required to define specific situations identified as worst case.
- What is the relationship between max SAR/mean SAR and duty cycle on temperature assessment (influence of the shape of the signal on T with regard to the time constant of temperature)? *(I do not understand this last item. The above is an edited version of the Partial Body Working Group Report by E.R. Adair)*

Final Session: Recommendations by Participants and Organizers.

1. Call for conference manuscripts from all participants: Submission deadline of 1 November 2004 to achieve peer-reviewed publication in a scientific journal.
2. Discussion of mechanisms for continued sharing of models and thermo-physiological data: collaborative modeling of the data as outlined in the above Working Group Reports.
3. Proposal for further thermophysiological research by Jack Hoopes to answer the near field temperature and blood flow questions by experiments in live pigs' heads exposed to RF energy (comparable to mobile phone signal). Measure both temperature and blood flow from the epidermal skin, dermal skin, muscle layer, and up to the skull. Approaching incrementally from the contralateral side, measure the blood flow and temperature from the inner skull, to the dura, into the brain tissue. After the pig is euthanized, take small tissue samples from the locations where temperature and blood flow were measured.
4. Conduct complementary dosimetric modeling of SAR in pigs' heads through existing MRI models by Joe Wiart's group and collaborators.

5. There are also opportunities for both measurements and modeling of temperature and blood flow in very young and young pigs' heads to approximate the exposure of children (Jack Hoopes).
6. A possibility of further thermophysiological research on rat heads, comparable to those for pigs described in item 3 above. These would be compared to existing SAR mapping of rat heads by Dave Nelson.
7. Consideration of a follow-up conference in a year, possibly in Rome.

IEEE ICES/COST 281 Thermal Physiology Workshop

Paris, France September 22, 23, 24 2004
Venue: INERIS, Parc technologique ALATA, 60 550 Verneuil-en-Halatte

Wednesday, September 22

Session 1: Introductory remarks, Technical details, Keynote address
Chair: René de Seze

1. M. Georges Labroye	Welcome from INERIS	09:00 - 09:10
2. Norbert Leitgeb	Welcome from COST 281	09:10 - 09:20
3. Ronald Petersen	Welcome from IEEE/ICES	09:20 - 09:30
4. Ralf Bodemann	Welcome from IEEE/ICES	09:30 - 09:40
5. René de Seze	Technical details of the Workshop	09:40 - 09:45
6. Eleanor Adair	Keynote address "Goals of the Workshop"	09:45 - 10:05

BREAK

Session 2: Environmental physiology and heat stress: whole-body and selected tissues - Chair: Dr. Peter Wainwright

1. P. Jack Hoopes	"Thermal dose requirements for tissues effect: Experimental and clinical findings"	10:35 - 10:50
2. Akimasa Hirata	"Maximum temperature increase in the head models of adult and child due to dipole antenna for different peak spatial average SAR values"	10:50 - 11:05
3. Niels Kuster	"Thermal thresholds of restrained RF exposed mice at 905 MHz"	11:05 - 11:20
4. E. B. Elabbassi	"Mobile phone user's head skin temperature increase and thermal modeling"	11:20 - 11:35
5. Eleanor Adair	"On the prediction of human physiological responses to RF energy deposition"	11:35 - 11:50

LUNCH BREAK

Session 3: Types of models currently available, including physiological and dosimetric models. Chair: René de Seze

1. Kenneth Foster	"Modeling the thermal response of biological systems exposed to radiofrequency energy: Uses and limits of baseline models.	13:15 - 13:30

2. Dusan Fiala "Modeling human thermal and perceptual responses to asymmetric radiation" 13:30 - 13:45

3. John Ziriax "Verification: RF dosimetry and thermoregulation modeling" 13:45 - 14:00

4. Jafar Keshvari "On the use of phantoms derived from magnetic resonance images (MRI) in computational RF and thermal dosimetry." 14:00 - 14:15

5. Theo. Samaras "Temperature calculations for RF radiation safety purposes." 14:15 - 14:30

6. Soichi Watanabe "Development of Thermal Simulation Models for Ocular Effects of MW and MMW exposures" 14:30 - 14:45

BREAK

Session 4: Possible techniques for combining models with classical physiological data and basic theoretical and experimental RF dosimetry.
Chair: Kenneth R. Foster

1. Joe Wiart "Bio heat equation modeling in the case of a handset" 15:15 - 15:30

2. D.A. Nelson & A.R. Curran "A high-resolution, whole-body model incorporating thermoregulation" 15:30 - 15:45

3. Larry Berglund "Human thermophysiological responses to partial-body exposure by directional radio frequency radiation in the 100 MHz to 11 GHz range" 15:45 - 16:00

4. P.R. Wainwright "Finite element solutions of the bioheat equation and their application in the development of radiofrequency protection guidelines. 16:00 - 16:15

5. Robert McIntosh "Electromagnetic and thermal modeling analysis at Telstra Research Laboratories." 16:15 - 16:30

6. J.J.W. Lagendijk "Treatment planning and safety modeling" 16:30 - 17:15

Discussion and plan for tomorrow 17:15 - 17:30

Depart INERIS for Creil Station 17:30

Train departs Creil station at 17:54, arriving Paris at 18:20

Thursday, September 23

Session 1: Initial dialogue concerning the number of discussion groups and the content of each. Chairs: René de Seze and Eleanor Adair 09:00 - 09:30

Group 1: Basic Thermal and Environmental Physiology Working Group
Chair: Eleanor Adair
Group members: René de Seze, Jack Hoopes, Sheila Johnston, Elmountasser Elabbassi, Bernard Billaudel
Topics to be covered: Pathophysiology, modeling techniques, available human data

Group 2: Whole-body Working Group
Chair: Kenneth Foster
Group members: John Ziriax, Soichi Watanabe, David Nelson, Larry Berglund, Antonio Faraone, A.R. Curran
Topics to be covered: RF dosimetry, modeling techniques, available human data.

Group 3: Partial-body Working Group
Chair: Joe Wiart
Group members: Niels Kuster, Theodoros Samaras, Peter Wainwright, Ronald Petersen, Ralf Bodemann, Dusan Fiala, Akimasa Hirata, Jafar Keshvari, Robert McIntosh, Győrgy Thuróczy
Topics to be covered: RF dosimetry, modeling techniques, available human data.

Session 2: Breakout groups for selection of Chairs, discussions, and decisions 09:30 - 10:15

BREAK

Session 2 (continued): Drafting of group reports. 10:45 - 12:00

LUNCH BREAK

Session 3: Presentation of group reports by group chairs 13:30 - 15:00

BREAK

Session 4: Roundtable discussion of possible modeling efforts and decisions on the best approach to take tomorrow. Chairs to be named. 15:30 - 17:15

Discussion and plans for tomorrow 17:15 -
Depart INERIS for Creil Station 18:00

Friday, September 24

Session 1: Continuation of discussion of the Pennes Bioheat Equation, the role of blood flow, types of appropriate models, proposed experiments, human variability in response to heating, whole- vs. partial-body exposure.

09:00 - 10:30

BREAK

Session 2: Two new breakout groups, whole-body and partial-body, to finalize the reports. Thermal physiologists were shared with the two groups.

11:00 - 12:00

LUNCH BREAK

Session 3: Presentation by David Nelson concerning the effects of variation (± 20%) in each of the terms in the modified bioheat equation. Additional discussion.

13:30 - 15:00

BREAK

Session 4: Concluding reports from the two breakout groups and decisions on the feasibility of a modeling approach to predicting human responses to RF/MW fields, both whole-body and partial-body exposures.

15:30 - 17:00

Finale: Recommendations by participants and organizers 17:15 - 17:30
Call for manuscripts from all participants

Departure by bus from INERIS to Chateau de Chantilly 17:30

Visit and Banquet at the Chateau 18:00 - 23:00

Bus to Paris 23:00

Au revoir

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IEEE ICES, INERIS, COST 281, EOARD/USAF

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ABSTRACTS OF PRESENTATIONS BY PARTICIPANTS

Session 1: Introductory remarks, Technical details, Keynote address.

THE IEEE INTERNATIONAL COMMITTEE ON ELECTROMAGNETIC SAFETY (ICES)

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The Institute of Electrical and Electronics Engineers (IEEE)[1] International Committee on Electromagnetic Safety was organized in 1960 as the American Standards Association C95 Committee co-sponsored by the Department of the Navy and the Institute of Radio Engineers (now the IEEE). Prior to 1988, C95 standards were developed by the American National Standards Institute (ANSI) Accredited Standards Committee C95 and issued as ANSI C95 standards. Between 1988 and 1990, the committee was converted to Standards Coordinating Committee 28 (SCC-28) under the sponsorship of the IEEE Standards Board. In accordance with policies of the IEEE, C95 standards are issued and developed as IEEE standards, and are submitted to ANSI for recognition as national standards. In 2001, the name "International Committee on Electromagnetic Safety," ICES, was approved by the IEEE Standards Association Standards Board for use by SCC-28 to better reflect the scope of the committee and its international membership. The membership of ICES stands at 116 with 44 members from outside of the US representing 22 countries; the ICES mailing list now approaches 400, including the many members and observers in the Subcommittees. An effort is now underway to broaden the scope of ICES to include product safety standards by including IEEE Standards Coordinating Committee 34 (product safety relative to the safe use of electromagnetic energy) under the ICES banner.

ICES follows a consensus process, open and transparent at every level, adhering to the rigid rules of the IEEE Standards Board. The committee and subcommittees are large and are open to anyone with a material interest. Although IEEE membership is encouraged, it is not required to join and participate on the ICES committee and subcommittees. The first of a series of RF safety standards (C95.1) was published in 1996; revisions of this standard were published in 1974, 1982, 1991, and a Supplement was published in 1999 and a revision is now undergoing ballot. In addition to the RF safety standard, ICES has developed a number of other standards including one that prescribes exposure limits at ELF frequencies (IEEE Std C95.6-2002), measurement standards, and standards on warning signs and symbols. ICES is now ready to ballot on a recommended practice on RF safety programs.

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[1] The IEEE is a non-profit, technical professional association of more than 360,000 individual members in approximately 175 countries.

BACKGROUND, RATIONALE, AND GOALS FOR THE ICES/COST 281 THERMAL PHYSIOLOGY WORKSHOP

Eleanor R. Adair, Ph.D.

For many years, scientists have tried to combine our knowledge of basic human thermal physiology with changes that occur when humans are exposed to thermal stress (heat). This stress can be natural environmental heating, elevated body temperatures during work and exercise, febrile states, and exposure to unusual heat sources such as radio frequency (RF) and microwave (MW) fields. The upper level of human thermal tolerance (~42 °C) is only a few °C above the normal core body temperature (37 ± 1 °C), which must be carefully controlled. Since data on human volunteers exposed to RF/MW energy are minimal, it is necessary to develop methods to predict how humans of various ages, genders, sizes, fitness, and environmental sensitivity would respond to different RF/MW frequencies, field strengths, durations, and modulations, confined to partial-body or whole-body exposures. Much current research concerns the thermal effects on the head and brain of RF energy from mobile phones and other electronic devices. Other research has quantified the physiological responses of human adults deliberately exposed to RF/MW fields. These exposures were either whole-body or partial-body, depending upon the exposure frequency. The primary goal of this workshop is to develop or utilize currently appropriate techniques for the prediction of thermophysiological responses of people exposed to RF/MW fields in assorted thermal environments. A primary focus on RF/MW biological effects, their dosimetry and prediction via assorted modeling techniques, would provide an enhancement of our capability to set science-based safety standards for human exposure to electromagnetic fields.

Session 2: Environmental physiology and heat stress: whole-body and selected tissues

THERMAL DOSE REQUIREMENTS FOR TISSUES EFFECT: EXPERIMENTAL AND CLINICAL FINDINGS. P. Jack Hoopes, Dartmouth Medical School, Lebanon, NH.

The purpose of this review is to present basic concepts relating thermal dose (time at temperature) to cell killing and tissue damage. The basic principles that govern the relationships between thermal exposure (temperature and time of exposure) and thermal damage, with an emphasis on normal tissue effects, has been summarized. Methods for converting one time-temperature combination to a time at a standardized temperature (cumulative minutes at 43° / CEM) are provided as well as some discussion about the underlying assumptions that go into these calculations. There are few in vivo papers examining the type and extent of damage that occurs in the lower temperature range for hyperthermic exposures (e.g. 39-42°C). Although not specifically calculated, the authors believe the CEM analysis for estimating an equivalent thermal does not retain a high degree of accuracy when temperatures are above 55°C or so. Therefore it is appears that estimation of thermal dose to effect at low (temperatures a few degree above baseline body temperature) and high temperatures are more difficult to assesses and quantify. It is also apparent from this review that the extremely large variation in the type and the quality of tissue damage endpoint and assessment available in the literature significantly reduces the ability to accurately determine the thermal dose associated with specific pathologic effects.

A detailed review of thermal thresholds for tissue damage in the majority of organs (based on what is detectable in vivo) has been assembled. The data are normalized using thermal dosimeter concepts. All data reported are for single acute thermal exposures.

MAXIMUM TEMPERATURE INCREASE IN THE HEAD MODELS OF ADULT AND CHILD DUE TO DIPOLE ANTENNA FOR DIFFERENT PEAK SPATIAL-AVERAGE SAR VALUES

A. Hirata[1], M. Fujimoto[1], J. Wang[2], O. Fujiwara[2], T. Shiozawa[3]

1. Dept. of Communications. Eng., Osaka University, Japan
2. Dept. of Electrical and Computer Eng., Nagoya Institute of Technology, Japan
3. Institute of Science and Technology Research, Chubu University, Japan

Abstract: In recent years, there has been an increasing public concern about the health implications of electromagnetic (EM) wave exposure with the use of mobile telephones. Therefore, various public organizations throughout the world have established safety guidelines for EM wave absorption. For RF near field exposure, these standards are based on the spatial peak SAR (specific absorption rate) for any 1 or 10g of body tissue. Note that the shape of averaging volume is dependendent on each standard. However, physiological effects and damage to humans by EM wave exposures are induced by temperature increases. A temperature increase of 4.5 ^{o}C in the brain has been noted to be an allowable limit which does not lead to any physiological damage (for exposures of more than 30 minutes). Additionally, the threshold temperature of the pricking pain in skin is 45 ^{o}C, corresponding to the temperature increase of 10-15 ^{o}C. In view of these circumstances, the temperature increase in the anatomically-based human head model for exposure to EM waves from handset antennas has been calculated in several works. In [1], we have revealed that maximum temperature increases in the head and brain are reasonably proportional to peak SARs in these regions. The shape of volume for calculating peak SAR used in [1] was cube. Note that peak SAR is averaged over 10g of contiguous tissue in the ICNIRP standard and tissue in the shape of a cube with a detailed regulation in the IEEE standard. This paper investigates statistically the maximum temperature increases in the head and brain for different SAR values. Namely, we calculate peak spatial-average SAR for different mass and averaging schemes. Our attention is also paid to those in the head models of 3-year and 7-year children [2], since it is concerned that children might be more vulnerable to any adverse effects of RF radiation than adults [3].

Reference

[1]A. Hirata and T. Shiozawa, "Correlation of maximum temperature increase and peak SAR in the human head due to handset antennas," IEEE Trans., vol.MTT-51, pp.1834-1841, 2003.

[2]J. Wang and O. Fujiwara, "Comparison and evaluation of electromagnetic absorption characteristics in realistic human head models of adult and children for 900-MHz mobile telephones," IEEE Trans., vol.MTT-51, pp.966-971, 2003.

[3] W.Stewart (chairman), Mobile Phone and Health. A report from the Independent Expert Group on Mobile Phones, Chilton, IEGMP Secretariat (May 2000).

THERMAL THRESHOLDS OF RESTRAINED RF EXPOSED MICE AT 905 MHz

Sven Ebert*, Clemens Dasenbrock+, Thomas Tillmann+, Niels Kuster*
*IT'US Foundation, ETH Zurich, Switzerland
+ ITEM Fraunhofer, Hannover, Germany

The objective of this study is the determination of the thermal regulatory and the thermal breakdown thresholds for restrained B6C3F1 and NMRI mice exposed to radiofrequency electromagnetic fields at 905 MHz. Different levels of the whole-body averaged specific absorption rate (SAR = 0, 2, 5, 7.2, 10, 12.6 and 20W/Kg) have been applied to the mice, and their body temperature was rectally measured prior, during and after the 2h exposure session in a parallel plate waveguide setup. For B6C3F1 mice, the thermal response was examined for three different weight groups (20g, 24g, 29g), both genders and for pregnant mice. Additionally, NMRI mice with a weight of 36g were investigated for an interspecies comparison. The thermal regulatory threshold of tube restrained mice was found at SAR levels between 2 W/kg and 5 W/Kg, whereas the breakdown of regulation was determined at 10.1±2.0 W/kg for B6C3F1 mice and 7.7±0.8 W/kg for NMRI mice, considering a confidential interval of 95%. The breakdown occurs between 6-14 W/kg.

MOBILE PHONE USER'S HEAD SKIN TEMPERATURE INCREASE AND THERMAL MODELING

Elmountacer Billah ELABBASSI & René DE-SEZE
INERIS DRC-TOXI, Parc ALATA, BP2, F-60550 Verneuil-en-Halatte, France

Mobile Phone (MP) user's skin increase temperature cause symptoms of thermal discomfort feeling. These symptoms may be due to thermal insulation, conduction of the heat produced in the phone by the battery currents and running of the radiofrequency (RF) electronic circuits, and electromagnetic field (EMF) energy absorbed by the user's head. Using a Luxtron 790 fiberoptic thermometer we measured the temperature of the temporal skin due to GSM-1800 MP radiated power (125 mW). We suppressed the EMF exposure by switching the RF signal from the antenna to a 50 Ω load. The ambient air temperature was 23°C and the MP was held in the normal position of use for 30 minutes to reach the thermal steady state. With a switched off MP, the increase in skin temperature was statistically significant 1.88°C. When MP was switched on, the increase was 2.93°C in reception mode, 3.29°C in emission mode without load and 3.31°C in emission mode with load. The temperature difference with or without load was not significant ($t_{17} = 0.707$; $p = 0.489$), which means that the contribution of EMF absorption to skin heating is negligible. The result suggests that the heat sensations reported by the MP users are mainly caused by thermal insulation and heat conduction from MP. The local skin heat distribution modeling by the Bio-Heat equation (BHE) must take in account -for the external heat source of the MP user's- the skin heat exchange modification by heat conduction and heat insulation with the environment since the thermal effect of the RF energy is negligible. This thermal heat exchange modification will influence other parameters of the BHE as the blood perfusion coefficient and the skin thermal conductivity.

ON THE PREDICTION OF HUMAN PHYSIOLOGICAL RESPONSES TO RF ENERGY DEPOSITION

Eleanor R. Adair, USAF Senior Scientist Emeritus,
Senior Research Scientist, Yale University

A major goal of this workshop was to explore the possibilities of predicting the basic physiological thermoregulatory responses of human beings exposed to assorted radio frequency and microwave fields. Until very recently, few or no laboratory studies of human volunteers had been conducted; instead, data collected on assorted laboratory animals have been surrogates for, and poor predictors of, human responses. I here report that, during a 10-year research program, eight studies have been completed at 4 different radio frequencies, 100, 220, 450, and 2450 MHz. While this frequency range is limited, it is also useful, accommodating whole-body energy deposition at resonant and near-resonant frequencies, and partial-body energy deposition at the two higher frequencies. An identical test protocol was used in each study; this involved a 30-min equilibration to the prevailing thermal environment, a 45-min RF (or sham) exposure to RF energy, followed by a 10-min re-equilibration. Several field strengths were tested in each study, many of which exceeded the current safety guidelines for controlled environments. In each study, the ambient temperature was controlled at 3 levels, 24, 28, and 31 °C. Six or seven adult volunteers (males and females) were tested in each study. A full battery of physiological responses was measured continuously; these responses included core (esophageal) temperature, 6 skin temperatures, metabolic heat production, sweating rate from back and chest, and local skin blood flow at 4 skin sites. Derived measures included heart rate, respiration rate, and total evaporative water loss. Judgments of thermal sensation, thermal comfort, perception of sweating, and thermal acceptability were recorded 4 times during each test. Reports of all but one of the 8 studies have been published in peer-reviewed journals and the report of the 8th study is currently in press. In general, each study demonstrated the great efficiency with which the core body temperature of humans is maintained at the normal level, close to 37 °C. This occurred even when the RF field strength exceeded the IEEE and ICNIRP exposure guidelines (controlled environment) by more than a factor of two. The mobilization of physiological heat loss responses (sweating and increased blood flow) were jointly responsible for the maintenance of normothermia in the subject volunteers who were tested. Voluminous data are available from these studies that can be used in various modeling efforts, such as were discussed in the IEEE ICES/COST 281 Thermal Physiology Workshop held at INERIS.

Session 3: Types of models currently available including physiological and dosimetric models.

MODELING THE THERMAL RESPONSE OF BIOLOGICAL SYSTEMS EXPOSED TO RADIOFREQUENCY ENERGY: USES AND LIMITS OF BASELINE MODELS

Kenneth R. Foster, Department of Bioengineering, University of Pennsylvania, Philadelphia PA 19104 USA kfoster@seas.upenn.edu

Much work over the past few decades has been devoted to modeling the absorption of radiofrequency (RF) energy in biological systems, which is of fundamental importance in dosimetry. Considerably less effort has been spent in understanding the resulting transport of heat in the exposed system which is important to understanding and predicting thermal effects of exposure to RF energy. In view of the anatomical and physiological complexity of biological systems, this is potentially a very complex problem - or not, depending on the information that one wishes to obtain from modeling studies. I review the uses of thermal modeling on three different distance scales: on a microscopic level to address the issue of potential "microthermal heating", on a millimeter to centimeter-scale level to address localized heating of tissues from partial body exposure to RF energy, and on the level of the whole body, to address thermophysiological responses in an intact organism. I argue that simple models can provide useful baseline information about the thermal response of biological systems to RF energy absorption with a minimum of adjustable parameters. More complex models can provide a finer-grained analysis, but this advantage can be offset by the requirement for ad-hoc adjustment of many parameters and the resulting difficulties in model verification. The choice of a model depends critically on the information that one needs from it, and investigators should not assume that more complex models are more reliable in answering specific research questions.

MODELING HUMAN THERMAL AND PERCEPTUAL RESPONSES TO ASYMMETRIC RADIATION

Dusan Fiala and Kuskana Kubaha

Institute of Energy and Sustainable Development, De Montfort University Leicester, UK

In this study, thermal and perceptual responses of humans exposed to directional and diffuse radiation ($10^{-7}<\square<10^{-3}$m) were modeled. Detailed three-dimensional geometry models of the human body at different postures were used to predict the geometry-related radiation characteristics of individual body parts. The models consisted of 10995 small surface elements, which were grouped into 19 body compartments and subdivided into 59 spatial sectors. The procedure involved voxel-based ray tracing techniques to predict the incident radiation at each of the 10995 surfaces elements.

Human responses were predicted by the IESD-Fiala physiological comfort model. This mathematical model is a multi-segmental, multi-layered representation of the human body with detailed information on anatomic, thermophysical and physiological body properties predicting human heat transfer phenomena that occur inside the body and at its surface. Each body compartment is subdivided spatially into sectors to enable detailed modeling of the effect of asymmetric radiation on humans. The thermoregulatory system of the model, which predicts the defence reactions of the central nervous system, and the incorporated thermal comfort model are based on statistical regression analysis of measured physiological and perceptual responses of reclining and exercising subjects exposed to cold stress, cold, moderate, warm, to hot stress steady state and transient conditions.

Verification and validation work using independent experiments showed good general agreement with measured data for human radiation characteristics, regulatory responses, mean and local skin temperatures, internal temperatures and overall and local perceptual responses for the whole spectrum of asymmetric radiation conditions analysed.

VERIFICATION: RF DOSIMETRY AND THERMOREGULATION MODELING

John Ziriax[1], Al Curren, William Hurt[2], Patrick Mason[2], and Stewart Allen[3]
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Radio frequency (RF) dosimetry modeling has been playing an increasingly important role in RF bioeffects research. In addition, standards setting bodies are considering modeling results which have been published without accompanying empirical data (IEEE SC4, 2004). Finally, it has been suggested that the next standard should be based on temperature change rather than specific absorption rate (SAR) (Chou, 2004). The prominence of RF modeling and the growing role of thermoregulation modeling places an added burden on RF bioeffects researchers to include empirical verification of both RF and thermoregulation models in their research efforts. The Brooks Dosimetry Project has typically met this need by modeling ongoing research projects as a parallel activity. While this tactic has met the need for empirical data to compare to model predictions, it is preferable to develop hypotheses and then design the appropriate empirical experiments. We are now in the process of planning an experiment with human subjects designed to test hypotheses borne from the combination of previous experimental results (Adair, et al., 2004), and RF and thermal modeling predictions. The successes and the errors will have important implications for our future bioeffects work.

DISCLAIMER: This work was funded by the U.S. Air Force and U.S. Navy (Project Numbers: 0602236N/M04426.w6, 0601153N/M4023/60182). The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as official Department of the Air Force, Department of the Navy, Department of Defense, or U.S. government position, policy, or decision unless so designated by other documentation. Trade names of materials and/or products of commercial or nongovernment organizations are cited as needed for precision. These citations do not constitute official endorsement or approval of the use of such commercial materials and/or products. Approved for public release; distribution unlimited.

ON THE USE OF PHANTOMS DERIVED FROM MAGNETIC RESONANCE IMAGES (MRI) IN COMPUTATIONAL RF AND THERMAL DOSIMETRY

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In setting the standards for limiting human exposure to RF electromagnetic fields, determining SAR and thermal effects play an important role. This is why the assessment of SAR and temperature increase inside tissues under various exposure conditions has been studied experimentally and computationally by many researchers.

To investigate the interaction of electromagnetic fields with physiological systems requires that the body of the human or the animal is taken into account. The problem can be approached in two ways. First is to make different experiments and body phantoms, which experimentally show the impact of electromagnetic fields on the human body. The second approach is numerical models to check and validate the experimental results. Generally speaking direct measurement of related quantities in human subjects are impractical. The alternative approach is to determine energy absorption and temperature rise caused by Electromagnetic fields (EMF) using numerical models in numerical calculations.

Phantoms are elaborated with the advance of computational processors. Introduction of powerful computers especially after 90's has made it possible to use MRI based models in RF and thermal computational dosimetry.

The aim of this paper is to examine limitations and benefits of MRI based models in RF and thermal computational dosimetry. By examining some of the previous studies which have used MRI based models and the study conducted by IEEE SCC-34, SC-2, WG-2, computational comparison of the SAM Phantom to anatomically correct models of the human head, some recommendations in interpreting the results of such studies is presented. Factors that should be taken into account when using MRI based models in RF and thermal computational dosimetry is considered too.

Phantoms and MRI based models used in previous studies will be introduced first. The author himself was involved in the aforementioned study conducted by IEEE SCC-34, SC-2, WG-2, which included 15 different laboratories. The study produced valuable experiences concerning the problems using MRI based numerical models. Problems encountered in that study will be discussed in detail.

TEMPERATURE CALCULATIONS FOR RF RADIATION SAFETY PURPOSES

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More than ten papers have been published in the peer-reviewed literature on the calculation of temperature increase in the head of mobile phone users. In these studies two models for heat exchange were mainly used, i.e., the Pennes BioHeat Transfer Equation (BHTE) and the model of DIscrete VAsculature (DIVA). Various numerical techniques (FDTD, FEM, ADI, the implicit method) were implemented in the solution of the differential equations that describe the thermal models. However, many of the parameters that are involved in these equations (e.g., blood flow) show a widespread variation in the existing literature. Furthermore, in a recent publication, Hirata and Shiozawa [1] have attempted to correlate the maximum temperature rise in the head with peak SAR values. Their results show that the numerical model of the head plays an important role in this correlation. Therefore, it would be of interest to investigate the variation in the resulting temperature rise inside the human body from RF exposure with respect to the (a) heat transfer models at tissue level, (b) numerical technique used, (c) model of the head (body) and (d) thermal parameters of tissues. Of further interest would also be a proposal for a model that can approach the 'worst-case' of temperature rise in the head (body) of a human exposed to RF radiation. Results will be presented that address some of the above points.

References

[1] A. Hirata and T. Shiozawa. "Correlation of Maximum Temperature Increase and Peak SAR in the Human Head due to Handset Antennas", IEEE Trans Microwave Theory Techn, vol. 51, no. 7, pp. 1834-1841, July 2003

DEVELOPMENT OF THERMAL SIMULATION MODELS FOR OCULAR EFFECTS OF MW AND MMW EXPOSURES

Soichi Watanabe[1], Akimasa Hirata[2], Kanako Wake[1], Masahiro Hanazawa[1], Yukihisa Suzuki[3], Masao Taki[3], Ikuho Hata[4], Masami Kojima[4] and Kazuyuki Sasaki[4]

[1]National Institute of Information and Communications Technology, [2]Osaka University, [3]Tokyo Metropolitan University and [4]Kanazawa Medical University

The basis of the safety guidelines to partial-body exposure to electromagnetic fields includes ocular effects. Most of in vivo studies on ocular effects have been investigated at 2450 MHz, or there are few data in millimeter-wave (MMW) band where various wireless applications will be deployed in near future. We have recently begun to study the ocular effects from MW band (2450MHz) to MMW band (up to 60 GHz). It is however difficult to sweep the ocular effects over such a wide band.
We are now therefore developing thermal simulation models in order to extrapolate the experimental results at several frequencies to those of the other frequencies. The developed models consist of voxel rabbit models and voxel human ones. The anatomically-based rabbit and human models have been developed based on CT and MRI images. For calculating the temperature increase in the models, the thermal physiological parameters of tissues assigned to these models are derived and optimized using measured data. Final aim of our study is to extrapolate from thresholds of ocular effects of rabbits to those of humans. In the workshop, we will present the summary of our recent experimental studies on dependence of ocular effects on thermal physiology and preliminary results of theoretical studies.

Session 4: Possible techniques for combining models with classical physiological data and basic theoretical and experimental RF dosimetry.

BIO HEAT EQUATION MODELING IN THE CASE OF A HANDSET

Joe Wiart*, Ahmed Ibrahiem * and Walid Tabbara**
*France Telecom RD, Issy les Moulineaux, France; **SUPELEC, Département de Recherche en Electromagnétisme (DRE / LSS), Gif sur Yvette, France.

The rise of temperature in the human head induced by a mobile phone depends on the exposure to the RF emission but also on the presence of the mobile phone itself. We have analyzed different numerical methods that are able to solve the Bio-Heat Equation (BHE); their advantages and limitations were compared. In particular, an implicit method based on the Alternating Direction Implicit technique (ADI) has been studied.

The rise of temperature in an anatomical model of the human head exposed to a GSM cellular phone operating at 900 MHz has been assessed using this method. The influence of the energy deposition compared to the influence of the box on physical phenomena such as convection, evaporation, and radiation has also been carried out.

In this configuration, the rise of temperature due to the presence of the phone box (1.5°C) is more than ten times the rise of temperature induced by the RF signal (0.1°C). These results will be presented and discussed.

A HIGH RESOLUTION, WHOLE-BODY MODEL INCORPORATING THERMOREGULATION

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A three-dimensional, voxel-based whole-body model ("ThermoReg") is being developed to simulate tissue heating from exposure to radiofrequency (RF) irradiation. The model works in conjunction with existing FDTD codes, which provide the local specific absorption rate (SAR) for each voxel. The thermal code solves a variation of Pennes bio-heat equation for a heterogeneous man ("Brooks Man") and incorporates thermoregulatory feedback to simulate local changes in blood flow (vasoconstriction/ vasodilation), sweating, and metabolic heating. Surface heat transfer mechanisms include convection, radiation, and evaporation. A shell-element version of the code is also being developed, for applications in which detailed analysis of internal heating is not warranted.

HUMAN THERMO-PHYSIOLOGICAL RESPONSES TO PARTIAL-BODY EXPOSURE BY DIRECTIONAL RADIO FREQUENCY RADIATION IN THE 100 MHz TO 11 GHz RANGE

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Soldiers, industrial workers and others may be exposed to radio frequency radiation (RFR) from radar, communication and other sources in the course of normal activities. To predict the effects of such, a popular Army human thermo-physiological simulation model was adapted for partial body exposure to RFR beam radiation. The model's skin is partitioned into radiated and non-radiated compartments that surround the larger core compartment. Skin blood flow, heat conduction and sweat rates can be different for the skin under the incident beam due to local temperature differences caused by RF energy absorption and their effect on physiological controls. Simulation results are compared with measured human physiological and subjective responses to beam radiation of 100, 450 and 2450 MHz on the back of lightly clad sedentary individuals in warm environments. The generally close agreement makes the simulation model a useful tool for activity and development planning.

FINITE ELEMENT SOLUTIONS OF THE BIOHEAT EQUATION AND THEIR APPLICATION IN THE DEVELOPMENT OF RADIOFREQUENCY PROTECTION GUIDELINES

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The thermal effects of electromagnetic radiation may be assessed by computation of the distribution of temperature rises within the body. Thermal dosimetry aims to relate these temperature rises to other metrics such as SAR or power density.

The most appropriate computational technique depends on the exposure conditions. In circumstances where the whole body is exposed at a level which causes elevation of the core temperature and consequent thermoregulatory responses, coarsely segmented models of the whole body have been used with some success.

Most theoretical studies of localized or regional heating use some variant of the heat equation. Traditionally, the Pennes "bioheat equation" has been used for this purpose. This is a partial differential equation, derived by consideration of the heat balance within an infinitesimal volume element. The bioheat equation has at least the virtue of simplicity. Heat transfer between tissue and blood is represented by a heat sink term, and only one parameter ω is needed to describe the blood flow within each tissue. Despite its shortcomings, comparison with results from more recent models has shown that it is still a valid approximation for many purposes.

This paper presents a brief review of some of the literature on computation of localized RF absorption in the head and eyes, using finite element and finite difference methods. This work has recently been motivated primarily by concerns over the implications of consumer mobile communication technologies.

An approach to computation of temperature distributions by finite element analysis is described, together with its application to two problems: Firstly, the exposure of the head to the field of a cellular telephone; and secondly, the "hot-spot" created in the ankle of an person under whole-body HF irradiation. Fine-scale anatomical models are used which have been derived from segmented voxel datasets.

Several models have been proposed to represent the regulation of local blood flow in response to changes in local temperature for certain tissues. A few of these have been incorporated in the model. This is a feature of the numerical model which, in a complete model, is separate and complementary to the overall control of blood flow in response to a central signalling mechanism. Central thermoregulation is not implemented in the NRPB model, which has so far been oriented towards local heating problems (for example, mobile phone exposure and "hot-spots").

The use of the specific absorption rate (SAR) as a surrogate for temperature rise is considered and illustrated with the aid of these two models. The difficulties of this approach are discussed. Particular problems arise from the differences in the definition of the SAR average in different national and international standards. Some future research needs are identified.

ELECTROMAGNETIC AND THERMAL MODELING ANALYSIS AT TELSTRA RESEARCH LABORATORIES

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Abstract – The Telstra Research Laboratories (TRL) have developed a numerical modelling environment for both electromagnetic (EM) analyses (using XFDTD from Remcom Inc) and thermal modelling analyses (using a finite difference model developed in house). The thermal modelling code can be used for human body studies and is based upon a formulation by Bernardi et al. of Pennes' bio-heat equation that also accounts for human thermoregulatory responses such as sweating. A comprehensive literature survey was also conducted to include the thermal properties of over twenty body tissues. SAR results calculated by XFDTD analysis can be input seamlessly into a subsequent thermal model, the output from which can then be viewed by the XFDTD post-processor. Confidence in the EM and thermal modelling tools has been obtained through comparison with semi-analytical solutions, as well as measured results obtained at TRL.

An important result arising from the human body studies has been that the distribution of induced tissue temperature parameter is much better correlated with the 10 g average SAR parameter, than with either the 1 g average SAR or the unaveraged SAR parameters. This has significant implications for the formulation of RF Safety Standards given the importance of thermal effects.

TREATMENT PLANNING AND SAFETY MODELING

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An overview will be given of the safety and thermal modelling research performed at the University Medical Centre Utrecht. This research line consist of:

- the development of a complete treatment planning system for hyperthermia treatment planning. This HTP system includes:
    - a FDTD based program for the computation of rf induced SAR distributions
    - the DIVA thermal model which incorporates the thermal influence of all discrete vasculature
    - visualisation, segmentation, vessel tracking and vessel generation software
    - optimisation of antenna arrays using full phase and amplitude control is being investigated

The quality of the system is being investigated using clinical hyperthermia patients. Tests are being performed on patients with tumours of the prostate and cervix.

- Data acquisition for treatment planning:
    - Dynamic contrast enhanced multislice CT (DCE-MSCT) imaging is being performed to measure tissue perfusion. These data is being correlated with in-vivo thermal washout data obtained during the hyperthermia treatments
    - Both CE-MSCT and MR angiography are being used to map the discrete vasculature.
    - Cadaver studies are being performed to investigate generic vascular patterns.
- Safety studies
    - A high resolution model of the orbit and eye structures is being constructed for both infrared and mobile telephone base station safety. The importance of the different tissue properties and blood flow have been investigated.
    - A pelvic model is being used to investigate the rf safety of modern high field strength MRI systems. The full description of the rf excitation coil and the determination of the full B1 field have been investigated.

Additional abstracts submitted by those who were unable to attend the workshop.

EXPOSURE TO RADIO FREQUENCY RADIATION (RF) - A PHYSIOLOGICAL PERSPECTIVE

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Body heating resulting from increased metabolic activity, environmental exposure, or a combination of the two places demands on the individual to dissipate the acquired heat load. The maintenance of heat balance in humans may be simply expressed as M = E + R + C, where M is metabolic heat production; and E, R and C represent heat loss by evaporation and heat loss (or gain) by radiation and convection. Typically, in response to increased core temperature, sweating and cutaneous vasodilation are initiated in a proportional manner to dissipate heat "sensed" by increased brain or "core" temperature and skin surface temperature. Similarly, significant heating of the skin surface will cause sweating and vasodilation. Significant heating of the skin from environmental exposure, encapsulation by protective clothing, directed skin heating or RF exposure in the absence of muscular exercise may result in a different scheme of physiological responses than that observed with heating the body core by muscular exercise. In addition, physiological strain during RF exposure may differ based on whether the radiation is absorbed by the skin or the core.

LOCALIZED RF ABSORPTION IN CRITICAL SURVIVAL ORGANS

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OBJECTIVES: The objective of this study is to identify the most sensitive and critical survival organs where the highest spatial peak SAR versus whole body SAR values are reported. Whole-body SAR should not be the only criteria used for dose-response evaluations of RF effects. Information about the location of maximal RF absorption inside the body and, thus, the most affected organ or tissue for various exposure conditions (frequency, orientation) is essential. More detailed analysis of variations in localized SAR in target organs of primary interest (heart, lung, brain, liver…) in relation to various range of organ sizes and shapes, frequencies, and orientations is needed. High SAR values near blood vessels may be less consequential than a high SAR deep in muscle, whereas high SAR in muscle tissue may be less consequential than high SAR in lung tissue or nerves. Thus, the localized SAR values in the brain and spinal cord seem to be more appropriate parameter for risk assessment than the whole body SAR.
METHODS: Spatial peak SAR in critical tissues/organs averaged over various masses were compared to whole body SAR average. Inter-comparison of the data represents a basis for setting criteria for more accurate numerical dosimetry or even for setting the appropriate ratio between whole body and localized SAR in health and safety standards. Localized resonance of individual target tissue/organ is important when considering

relationship between average SAR and variety in exposure conditions. The focus is on maximum ratios between spatial peak SAR and whole body SAR average for different survival organs (white and gray matter, heart, inner and outer lung, liver, muscle, cerebral spinal fluid, nerve spinal, heart) in relation to various frequencies and orientations. The Finite Difference Time Domain (FDTD) program was used to predict spatial peak and whole body normalized SAR values (W/kg per mW/cm^2) in 3 mm^3 anatomical man model. The FDTD code and digital anatomical models were developed jointly by U.S. Naval Health Research Center Detachment and U.S. Air Force Research Laboratory, Brooks AFB, Texas. The model was processed in the far field conditions at the resonant frequency (70 MHz) and non-resonant frequencies in the range between 35 - 2000 MHz for MEHK orientation. In addition, other orientations (MKEH, MHEK) of the model to the incident fields were used where no substantial resonant frequency exists. The SAR data were used as an input to the core of the averaging algorithm to calculate the spatial peak SAR (W/kg per mW/cm^2) averaged over 1 g and 10 g of tissue for various exposure conditions.

RESULTS: We found the highest spatial peak SAR value (10.3 W/kg per mW/cm^2 averaged over 1 g and 7 W/kg per mW/cm^2 averaged over 10 g) as well as highest ratio (over 40) for muscle at resonant frequency (70 MHz) at MEHK orientation. According to presented data, the muscle seems to be the primary site of interaction where the great majority of incident RF energy is absorbed. Several other peaks were found around 600 MHz and 1800 MHz, respectively. At MKEH and MHEK orientations, lower values with no significant maximum are reported. When comparing with muscle, relatively lower absolute SAR values and ratios between spatial peak SAR and whole body SAR average were observed in other selected tissues. These ratios for cerebral spinal fluid and nerve spinal were close to 30 at 200 MHz and 15 at 70 MHz at MEHK orientation, respectively. At MKEH and MHEK orientations, lower ratios were observed. Energy absorption within the brain (gray matter, white matter) was something lower and has reached its maximal value at MKEH orientation between 600-1000 MHz. The maximal ratios between peak localized SAR and whole body SAR were around 10. In contrast, relatively low ratios between spatial peak SAR and whole body SAR average were found in heart, liver, lung outer and lung inner (between 3 and 7). When choosing 1 g averaging volume, the ratios between spatial peak and whole body SARs anywhere in the body were normally much higher than factor of 20. On the other hand, the ratios obtained by 10 g averaging volume were close to factor of 20. This was particularly true for muscle, skin, cerebral spinal fluid and fat. For other critical survival organs, the ratios between spatial peak and whole body SARs obtained by both averaging volumes were lower than 20.

CONCLUSION: We found that muscle is the primary site of interaction of electromagnetic energy and, thus, the highest absolute SARs as well as relative ratios between spatial peak and whole body SAR average were reported (up to factor of 50). Preliminary results have revealed that high water content tissues including muscle absorb more energy from RF fields than less wet tissues and are, thus, more lossy. Since muscle is spread through the whole human body, it forms complex multiple tissue layers and affects the localized SAR values in the majority of the surrounding tissues and organs. Since the highest ratios were observed for skin, fat and muscle in all applied combinations of orientations and frequencies,

these findings indicate that selected central organs are reasonably well shielded by these tissues, in particular the muscle where the greatest portion of the incident energy has been absorbed. The present work showed that spinal cord and cerebral spinal fluid could be listed among the tissues with medium absorption coefficient since the ratios between spatial peak and whole body SAR were lower than factor of 30 for all applied combinations of orientations and frequencies. The ratios between spatial peak and whole body SAR in other central organs under investigation (inner and outer lung, liver, heart) were lower than factor of 10 and, thus, the localized absorption of incident RF energy was close to the whole body SAR average.